

# Attachment 1

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# *Improving Aircraft Beddown: Estimates for Conducting Combat Operations*

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## ABSTRACT

To conduct effective combat operations, the Air Force needs to deploy the right mix of aircraft to the right airfield. When too many aircraft are assigned to an airfield, its infrastructure is overwhelmed and aircraft mission effectiveness is degraded. Our current planning capability and our analysis of current and future scenarios must be logically flexible and robust enough to account for the changes in world politics, where bases we planned to use today might not be available tomorrow.

To improve AFSAA's (Air Force Studies and Analyses Agency) capability to quickly estimate beddown plans, we made enhancements to our logistics-planning tool, CBLP (Capabilities Based Logistics Planner). We made it easier to identify potential airfields, and added dynamic tables to display the reduced capabilities of the airfields, as aircraft are bedded down. These enhancements have been used at AFSAA to build more realistic beddown plans for use in our analysis. A web-based version of CBLP is being developed for demonstration in JEFX (Joint Expeditionary Forces

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## INTRODUCTION

Determining the best way to bedown aircraft to support a contingency is a balance of many factors; the primary categories of these factors are: political, strategic, and logistic.

Political factors include host nation support of their airfields for USAF operations. The number of aircraft bedown at a host nation airfield will depend on the level of their support. It is relatively easy for a planner to account for the political factors, when building a bed down plan. Accounting for the political factors first involves determining the potential host countries for airfields. Often, the host country will limit which airfields can be used, and how much of those airfields we will be allowed to use. They may also place other limits on the types and quantity of

operations we conduct. For example, we might be unable to fly combat missions, such as bomber and fighter missions, due to the airbase's proximity to cities or areas of religious importance. The political factors are very dynamic and can quickly change based on a contingency or other events.

The strategic factors for bedding down aircraft involve assuring runways meet the specifications for combat operations, that the aircraft are within range of their targets, and have a sufficient capability to defend against threatening weapons systems that can attack the airfield, such as surface-to-surface missile systems. Strategic factors are more difficult to measure, because they require a balance among the runway capabilities, being within combat range of potential targets, and the ability of enemy weapon systems to strike at the airfield. The closer the aircraft are bedded down to their targets, the more sorties they can potentially conduct; but, this could also make the airfield more vulnerable to enemy weapon systems. The planners need to find the correct balance by finding suitable airfields within sufficient combat range of potential targets, but with a sufficiently low risk of being successfully attacked by enemy. Since the targets and threats are usually spread out, multiple airfields can be used to cover the target set.

Logistic factors include parking space, fuel and munitions availability, and other airfield infrastructure constraints. These factors measure the ability to support specific aircraft operations. The Air Force is currently not good at quickly assessing logistics factors across a theater; but it has well defined processes to assess the ability of individual bases to support a specific set of aircraft, typically within 24-hours. What the Air Force lacks is a tool that quickly and accurately measures logistic constraints at the theater level.

Planners can identify the political and strategic factors, because they are either simple or methodically measurable. However, planners have minimal logistical considerations to build an initial beddown plan. Models such the Logistics Contingency Assessment Tools (LOGCAT) have the capability to help compute logistics requirements; but LOGCAT requires a large investment in data research and becomes time and manpower intensive to make a quick assessment. The studies and analyses of using host nation airbases typically drive planning and acquisition decisions. Since these decisions do not account for the logistic constraints of how we fight, they handicap future operations. However, planners do their best to develop beddown plans for individual airbases using the processes the Air Force defined. Before an initial beddown plan is executed one or more agencies review the logistics constraints of each airbase to determine if the bed down at each airbase is logically supportable.

Several analytical tools could be used to review logistical constraints; but planners need to be able to take into account logistics constraints at the beginning of the advance planning process, along with the political and the strategic constraints. The most critical of the logistic factors is in determining if there is enough ramp space to park the aircraft. Next are the constraint of munitions and then the fuel constraints. Ramp space is the most critical because building additional ramps is material, equipment, and time intensive. The tool used by planners to study parking is the Contingency Aircraft Parking Planner (CAPP), which is used to develop the parking plan that places the aircraft on the aprons, and ensures there is enough room for the aircraft. While CAPP is extremely useful for determining if there is room to park the aircraft at the base, it is time

intensive, which means it cannot be used to quickly explore multiple locations with multiple combinations of aircraft to beddown. There is also a level of training required for the user to ensure that a valid parking plan is generated.

To improve this process, planners need to be able to take into account logistics constraints at the beginning of the advance planning process, along with the political and the strategic constraints. The most influential of logistics factors is parking; therefore we decided to tackle parking first.

### SURVEY OF AVAILABLE TOOLS

When we surveyed the available tools that are available to determine parking capability at an airfield we found two. They are the Contingency Aircraft Parking Planner (CAPP) and the Capabilities Based Logistics Planner (CBLP).

CAPP uses imagery to construct the layout of a base, which allows the user to trace imagery of the airfield and highlight runways, taxiways, parking areas, hazards, and other details. The dimensions of the different airfield pieces and how they are connected are the inputs read by CAPP. The users can then start parking aircraft and make sure the aircraft are parked in suitable locations, taking into account the parking regulations. An advantage of CAPP, which makes it very useful, is that it provides an accurate aircraft parking plan, however it requires some level of user expertise, combined with a high level of user input. The problem with using CAPP at the beginning of the planning process is that it is not very practical for quickly estimating and comparing the parking capability airfields across a theater, weighing their individual strengths and weaknesses.

The second tool surveyed is CBLP. CBLP had the advantage of having a global perspective and the capability to quickly estimate parking capability of the airfields.

CBLP uses the AAFIF (Automated Air Facilities Intelligence File) as its primary data source, which is a NIMA (National Imagery and Mapping Agency) product that includes airfields around the world. While the Air Force maintains databases that have better data for select airfields that they commonly use, the AAFIF is the best single source for airfields that the Air Force is not currently experienced in using. The disadvantage of CBLP is it uses a rudimentary process for picking bases from lists and it does not consider sufficient details for estimating the parking capability. The calculations are oversimplified because they use the total square footage of ramp space at the airfield; with each aircraft type having an estimated square footage requirement. As aircraft are parked at a base, their required square footage is subtracted from the base's total. The problem with this process is that it ignores the geometric intricacies of the parking problem and can significantly overestimate the parking capability of an airfield.

The conclusions from our survey were that CBLP is the best option; but it would need some improvements. It was chosen for two reasons: first, it provided an initial framework to build upon, and second, planners are familiar with CBLP. Being recognized in the planning community facilitates gaining support for improvements and makes it easier to get feedback.

### OVERVIEW OF IMPROVEMENTS

We improved CBLP in two different areas. The first was to make the process for selecting candidate airfields more powerful. The second was to improve the estimates of parking capability of airfields, and to create a user interface for parking the aircraft.

#### **Selecting Candidate Airfields**

The original CBLP allowed the user to filter a list of airfields by possible

countries, which is useful if you already know the countries and airfields you are interested in. If not, you need to use another tool or tools to determine the airfields and bases needed, and then input those answers into CBLP.

We wanted to make a more dynamic interface that gave the user the ability to start with the entire world, and then zoom in on areas of interest. The following capabilities are then provided to the user:

1. Select a box on the map, within which to find airfields.
2. The model responds with a list of countries that have area within the box. The user can exclude one or more of the countries, which then excludes airfields located within their borders.
3. Allow the user to add countries from outside of the box.
4. Allow the user to define threat points on the map, along with a distance. This defines a threat ring; airfields that fall within the threat rings are excluded.
5. Filter possible airfields by runway length, width and LCN (Load Classification Number, which is a measure of the strength of the runway). Values can be individually changed, or by selecting an associated aircraft type which will then be used to set the minimum length, width, and LCN. Aircraft types are: bomber, fighter, none, tactical airlift, or strategic airlift.

From the list of airfields generated from the above criteria, the user selects the candidate bases that can be used to beddown aircraft. The user can then set the criteria to new values and select additional airfields.

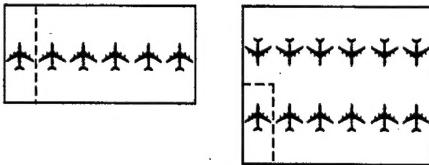
### **Beddown Aircraft**

The original CBLP allowed a user to choose which aircraft to beddown at an airfield. With no aircraft at an airfield,

CBLP would display a full green bar for the ramp space usage, and label it at "100%." Once a user had placed the aircraft at airfield, CBLP would decrease the size of the bar and display the percent of ramp space that remained free. If an airfield's parking capacity was exceeded, then the bar is colored red, and the percent over its capacity is displayed. The total ramp space square footage for an airfield is a quantity from the AFFIF. Each aircraft type has an associated parking square footage requirement. For each aircraft bedded down at a location, its associated parking requirement is subtracted from the airfield's remaining free ramp space. This total is then used in the following equation to determine the percentage of free apron space.

$$\begin{aligned} \text{UsedRampSpace} &= \sum_{i=1}^{\text{VAircraft}} (\text{SpaceRequired}_i * \text{Quantity}_i) \\ \%Free &= \frac{\text{TotalRampSpace} - \text{UsedRampSpace}}{\text{TotalRampSpace}} \end{aligned}$$

There are two problems with this process. The first is that the amount of ramp space required per aircraft is dependent upon the parking configuration of the aircraft. The space required to park an aircraft does not include just the length of the aircraft multiplied by its width; it also includes the necessary room to taxi between the rows of aircraft, so that they can freely maneuver. Depending on the parking configuration of the aircraft, the amount of taxiway space required per aircraft will change. Figure 1, below, shows a simplified example, assuming that each row of aircraft parking will have room to taxi on either side of the row. If there is one row of aircraft, then the area required per aircraft is the area it covers plus the area in the taxi area in front and behind the aircraft. This is shown in the parking diagram on the left side of Figure 1.



**Figure 1. Area required per Aircraft**

This is then compared to parking the aircraft in two parallel rows where the aircraft will share the inner taxi lane. The space required for each aircraft now is the area it covers, plus the area in one of the taxiway on the outside, plus half of the inner taxiway. This is shown in the parking diagram on the right side of Figure 1.

Going from one to two rows of aircraft reduced the per aircraft taxi space requirement from  $x2$  to  $x1.5$ . If an additional taxiway is added perpendicular to the rows of aircraft, then the taxi space requirement is dependent on the number of columns as well.

The second problem is that this process ignores the geometric nature of this problem. An airfield's ramps are set geometric shapes, and the aircraft are also set geometric shapes that are parked using specific rules. CBLP ignores the geometric nature of the problem. This can generate results where the equivalent of a single aircraft is parked on multiple aprons. It can also mean that a long thin apron designed for small aircraft could have enough area to park a much larger aircraft, even though the apron is not wide enough to physically fit the aircraft. To the extreme, an apron that is 100 feet wide and 2000 feet long, with an area of 200,000 sq ft, is equivalent to an apron 200 feet by 1000 feet, which also has an area of 200,000 sq ft.

### PARKING HEURISTIC

#### **Survey Different Techniques**

To develop a better way to estimate the parking capability of an airfield, we first

surveyed several possible available methods. The methods we looked at were: regression, optimization and packing algorithms, and the algorithms used in CAPP.

A simple regression is what was used for the initial CBLP approach. The problem with using regression for estimating the parking capability is that its geometric nature means that the solution space for a single aircraft type on an apron is a step based function. When combined with multiple aprons and multiple aircraft types, the solution space quickly becomes too complex for regression.

Optimization and packing algorithms offer a definite possibility for solving this type of problem. The basic technique is to divide the aprons into small blocks, and then define the rules for the possible ways they can be put together to represent a valid parking structure. There are several problems with using this technique for this application. They include the requirement for specialized software to solve and the amount of time it would take to solve a set of problems is not be conducive for this use in exploring different beddown options. The purpose for the parking heuristic is to generate a quick estimate based on incomplete data. There is minimal value in going from a good enough answer to the optimal solution, when the actual quantity is based of data and factors not readily available. The difficulty in the formulation, the uncertainty in the amount of time this technique requires solving the problem and the cost of specialized solvers made this technique unappealing for this application.

The algorithms used in the base beddown program CAPP offered another possibility. Unfortunately there is little to no documentation on the algorithms used in CAPP. Initial research revealed that the algorithms used would not be able to calculate the results within preferred time limit, plus we were unable to acquire the

algorithm within the time limit for use in this project.

The final option, and the one we chose to implement, is to develop a specialized heuristic. Heuristics involve techniques that can quickly search a solution space for an answer. They are not guaranteed to find the optimal answer; however since we are working with incomplete data, "close enough" is sufficient. One of the advantages of using a heuristic approach is that there is more flexibility in how the problem is formulated. Instead of breaking the apron into a matrix of squares, we can instead define a reduced set of possible solutions to search.

### Approach Overview

The development of the heuristic first involved determining several different basic styles for parking the aircraft. The styles vary based on parking at  $45^\circ$  and  $90^\circ$ , and the amount of maneuvering room available.

After developing the parking styles, we developed an interactive process for building and searching a limited set of possible parking plans. The process is described through three levels of complexity. The simplest is how to calculate the quantity of a single aircraft type that can be parked on a rectangular apron. The second level is how multiple aircraft types can be parked on the same apron. The third and final level is how multiple aircraft types can be parked on multiple aprons.

### Parking Styles

We created several parking styles to be used as templates for determining the number of aircraft that can fit on a ramp. The primary Air Force publication used in the creation of the parking styles was: Air Force Handbook 32-1084 (1 September 1996), it is a Civil Engineering publication titled: Facility Requirements. Section 2.17

provides detailed information on how aprons are designed. We use this information to determine how we can use existing aprons.

The parking styles we developed are tailored to the amount of information provided on the airfield. They are varied based on the angle the aircraft are parked,  $45^\circ$  and  $90^\circ$ , and the amount of maneuvering room available. The maneuvering room varies in two areas. The first area is being able to maneuver on and off the ramp; this ranges from not being blocked in by other aircraft to where other aircraft will be required to move to allow the aircraft on the ramp. The second area is the amount of maneuvering required by the aircraft to get into its parking spot; this varies from being able to pull forward into and out of its spot, to having to be backed into its spot, and then being able to pull forward out of the parking spot. The overall goal for the parking styles is to be used to generate a realistic and conservative estimate of the number of aircraft that can be parked at an airfield. When in doubt, these parking styles will err on the conservative side, because it is easier to add aircraft to an airfield, in the planning process, than to remove them.

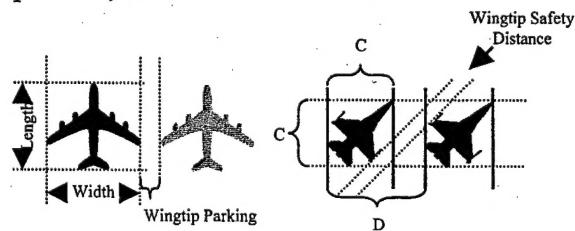
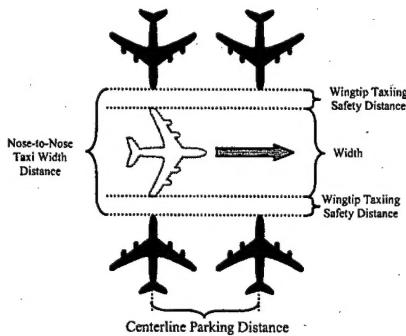


Figure 2. Dimensions for Parking

To be able to accurately park the different aircraft, several dimensions and distances are needed, shown in Figure 2. The simplest are the length and width of the aircraft, which are used when parking the aircraft at  $90^\circ$ . When aircraft are parked at  $45^\circ$ , a distance called the block distance is used, denoted by C, in Figure 2. (Air Force Handbook 32-1084: 33) If no other distance is provided, the value for C can be estimated

by multiplying the width by 1.414. This value is derived from an equilateral right triangle, with the hypotenuse equal to the width of the aircraft and the other sides equal to the block distance, the equation is:  $a^2 + b^2 = c^2$ , where  $a = b$ . When aircraft are parked in rows, they are the wingtip safety distance apart. This is the safety distance required between the wingtips of two aircraft. When the aircraft are parked at  $45^\circ$ , this distance is included with the block distance and denoted by D in Figure 2. The value D can be found by adding 1.414 times the wingtip safety distance, to the block dimension of the aircraft.

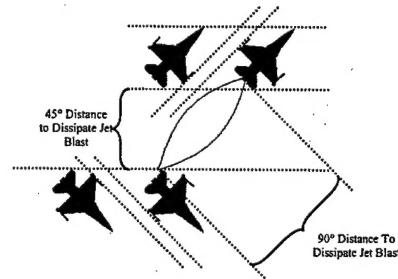
To allow an aircraft to maneuver around other aircraft to get on and off the apron, space on the apron is reserved for taxiways. It is important to note that the space reserved for a taxiway on the apron could run parallel to, and be right next to, an actual parallel taxiway to the apron. In which case, a planner might want to use a tool outside of CBLP, like CAPP, to adjust the parking plan.



**Figure 3. Nose-To-Nose Taxiway**

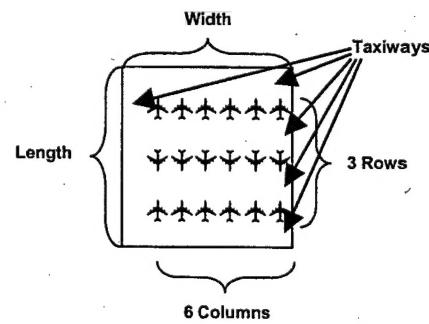
Figure 3 shows how taxiway space is reserved on the apron when aircraft are parked nose-to-nose. The taxiway space reserved needs to be as wide as the plane, plus the wingtip safety distance on both sides of the wing. When aircraft are parked nose to nose, and there is enough room to taxi between them, then that distance is equal to the width of the plane, plus two times the wingtip safety distance. When

aircraft are parked tail-to-tail, the distance is the maximum of the distance if they were parked nose to nose, and the maximum jet blast distance to keep from damaging the aircraft behind it. When parked at  $45^\circ$  the distance for the jet blast is divided by 1.414, and that distance is then compared to the nose to nose parking distance, as shown in Figure 4.



**Figure 4. Tail-To-Tail Taxiway**

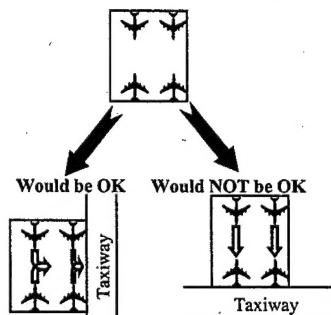
To clarify definitions, Figure 5 outlines how each row will go down the width of an apron, and the rows will be perpendicular to the length. Note, the length and width do not necessarily correspond to the longest and shortest distance. A taxiway refers to the reserved space on the apron to maneuver aircraft around other airplanes. The reserved space is entirely on the apron, and could be adjacent to a parallel taxiway.



**Figure 5. Row and Column Orientation**

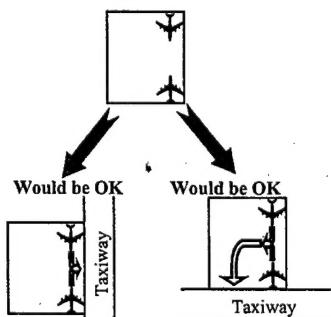
The biggest consideration in developing the parking styles is a lack of data on how the taxiways and aprons are connected. Therefore the parking styles are setup so that they are usable if the taxiway connects along any edge. Figure 6 is an

example of a parking plan that does not ensure sufficient maneuvering room around other aircraft. As shown, if the taxiway connects on the right or left sides of the apron, the aircraft can maneuver off the apron. However if the taxiway connects to the top or the bottom, then two of the aircraft block the other two aircraft in. Since we do not know the entry and exit points, and we want to make sure we have a conservative estimate that parking plan would not be allowed. This would not be considered an acceptable parking style.



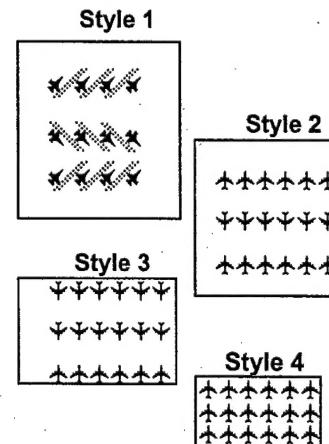
**Figure 6. Example: Poor Parking Style**

Figure 7 demonstrates how by removing two of the aircraft, maneuvering room is now assured, no matter which side of the apron the taxiway connected. Note: An additional aircraft could be placed on the apron, for a total of three, and maneuvering room would still be ensured. The reason this is not done is that the parking styles are also designed so that the apron can be divided into different parts. By having a taxiway go all the way through in both directions, aircraft parked in other sections can maneuver through this section if needed.



**Figure 7. Example: Good Parking Style**

In addition to ensuring sufficient maneuvering room, several other resources were used in the development of the parking templates or styles. They included: the air force handbook, airfield beddown plans, airfield satellite imagery, and conversations with airfield managers and former pilots. Based on these resources, four different parking styles were created for the heuristic, as shown in Figure 8. They range from having a lot of maneuvering room, to having no maneuver room. All styles have the aircraft parked in rows where they park nose-to-nose and tail-to-tail.



**Figure 8. The Parking Styles**

The most maneuverable style, style 1, consists of the aircraft parking at  $45^\circ$  with respect to the apron. Each row has a taxiway on all 4 sides. For the remaining three styles, the aircraft all park at  $90^\circ$ . The second parking style has taxiways that are parallel to the rows of aircraft and are on both sides of the rows, as well as a taxiway that is perpendicular to the rows of aircraft. This style allows the aircraft to pull forward into and out of their parking spots.

Parking style 3 requires that some of the aircraft will have to back into parking spots. Each row has at least one taxiway parallel to it, inner rows will have a parallel taxiway on both sides, and the outer rows will not have taxiways on the outer sides.

Also, one taxiway is perpendicular to the rows.

The final style, style 4, packs the aircraft without any maneuvering room. The only separation between the rows of aircraft is the wingtip safety distance. If the aircraft are parked using this style, then aircraft will be blocked in.

Of the four parking styles, two of them are the primary parking styles used in the CBLP upgrade. The first parking style, where the planes are parked at  $45^\circ$ , is used to park fighter aircraft. All remaining aircraft are parked using the third parking style, which is where aircraft will have to back out of some of the parking spots. The user has the option to change the parking style used for fighters, as well as the parking styles used for the remaining planes.

### Specialized Heuristic

The goal that drove the development of the heuristic was to quickly generate a conservative estimate of the number of an aircraft type that could be parked at an airfield, taking into account what is already parked.

One of the considerations is that imperfect and incomplete data is used to create the estimate. A final beddown plan needs to take into account additional pieces of information like the apron-taxiway configuration, and hazards that would prevent aircraft from being parked in certain locations.

Since imperfect data is being used, there is little point in spending an exorbitant amount of time generating the perfect answer, since it will probably not be correct anyway. Instead, the goal is to find a reasonable solution that can later be improved with refined information.

Several key assumptions are used in the development of the heuristic. The first assumption is that aprons are rectangular. If the apron is not rectangular, it is assumed

that rectangular dimensions can be used to approximate its capability. This assumption is partly driven by the data. The AFIF will provide only two dimensions for the apron, approximating irregular shaped aprons as rectangles. The second is if there is enough room on the apron for the aircraft and the runway is sufficient for the aircraft, then there will be sufficient taxiways for the aircraft to go back and forth from the runway. Third, it is assumed that the problem will be solved iteratively, with user inputs. The purpose of the heuristic is not to take a list of bases and aircraft and optimally bed them down. Instead, the heuristic is used to give the user insights into where different aircraft can be bedded down, given what is already bedded down. The final assumption is that the beddown generated will only be used for an estimate or as a starting point in the planning process. If the beddown plan is going to be executed, a more thorough survey of the beddown plan and airfield needs to be done.

The heuristic will be explained in three different phases. The phases will increase in the complexity of the problem being solved. The first phase will focus on determining how many of one type of aircraft can fit on a single apron. The second phase will explore parking multiple types of aircraft on an apron. The third phase will involve parking multiple types of aircraft on to multiple aprons. A visual example is at the end of the first two phases.

#### Phase I: One aircraft type/One Apron

Depending on which aircraft style and aircraft type is being parked, it is relatively easy to determine the number of rows and number of columns of aircraft will fit on an apron. For example, Figure 9 contains simplified formulas to determine the number the number of columns that will fit on an apron. They apply to the second parking style, where aircraft are parked at

90° and do not have to back out. The equation that calculates the number of rows is simplified in that it does not account for

the possibility of there being different taxiway widths when aircraft are parked nose-to-nose vs. tail-to-tail.

$$\# \text{Rows} = \text{RndDown} \left( \frac{\text{Apron.Length} - \text{Taxiway.Width}}{\text{Aircraft.BlockDist} + \text{Taxiway.Width}} \right)$$
  

$$\# \text{Col} = \text{RndDown} \left( \frac{\text{Apron.Width} - 2 * \text{Taxiway.Width} + \text{Aircraft.WingtipSafetyDist}}{\text{Aircraft.BlockDist} + \text{Aircraft.WingtipSafetyDist}} \right)$$
  

$$\# \text{Aircraft} = \# \text{Rows} * \# \text{Cols}$$

**Figure 9. Approx. Formulas for # AC**

The equation that changes is the calculation for the number of rows. The actual process to calculate the number of rows is as follows. First the whole number of double rows that will fit is calculated. A double row is defined as two rows of aircraft facing each other. The nose-to-nose taxiway distance is used to separate aircraft facing each other. The tail-to-tail taxiway distance is used to separate aircraft facing away from each other. The distance used by the one or more double rows is subtracted from the length of the apron. This distance is then used to determine if there is room for a final single row of aircraft, with the appropriate taxiways.

To find the number of aircraft that can park, the number of rows is multiplied by the number of columns. Then the length and width of the apron are switched and the new number of aircraft that can now fit is calculated. The maximum of these two values is referred to as the maximum number of aircraft that can be parked on the apron. It is in fact the maximum that can be used applying the parking style.

It can sometimes be possible for a greater number of aircraft to be parked if some of the rows are perpendicular to each other. This possibility is not currently taken into account in estimating the maximum number of aircraft. However, it may be found by parking a set of aircraft, and then

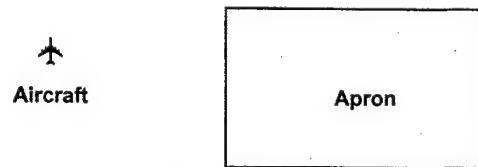
finding that the number of parking spots remaining for the same type of aircraft is higher than would be expected.

Following is a visual step-wise example of this process. Note: The images are not to scale.

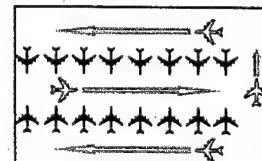
STEP 1- Figure 10 shows the aircraft to be parked and the apron to park it on.

STEP 2- Figure 11 illustrates that two rows and eight columns fit on the apron in this orientation, with the necessary taxiway space reserved. For a total of two \* eight = sixteen aircraft on the apron.

STEP 3- When rotated, in Figure 12, the apron fits four rows and four columns, or sixteen aircraft. Since both orientations can park sixteen aircraft, the maximum parking for the apron is sixteen aircraft.



**Figure 10: Step 1-Aircraft to Park on Apron**



**Figure 11. Step 2-Calculate # Rows & # Columns**

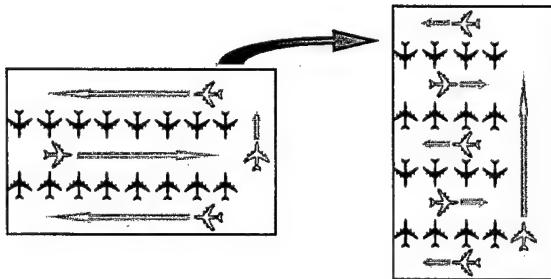


Figure 12. Step 3-Rotate 90°'s and recalculate

### Phase II: Multiple aircraft types/One Apron

From the previous phase, given a rectangular space of free apron, an aircraft type to park, and the parking style to use, the maximum number of aircraft that can fit on the space can be found. The next step is to be able to park multiple types of aircraft on the same apron. To do this, multiple parking solutions should be searched, since more aircraft might fit in one configuration than in another. Also, the apron space needs to be divided into the space currently being used, and the space that is available. Finally, if the space for taxiways is reserved on an apron, and it is adjacent to a free space, then this information is associated with the free space. When aircraft are parked on the free space they will take into account the adjacent taxiway. If the taxiway is smaller than what the aircraft being parked requires, then it is expanded so that both types of aircraft can use it.

Every time a squadron of the same aircraft type is parked on an apron, four possible solutions are searched. Of these solutions, only the one(s) that have room to park all of the aircraft to be parked are used. The first way is by filling up entire rows of aircraft first. The second is by filling up entire columns of aircraft first. The third and fourth ways are the same as the first two, except that the apron is rotated 90°.

The unused space on the apron for the different solutions is stored in two different ways. The first way is the rectangular free space is initially the entire apron, but then is

reduced by rows of aircraft. The second way is the unused space on the ends of rows. Figure 13 shows how the free space is reserved when aircraft are parked by row or by column, for both orientations. From the diagram it can be seen how the free space is similar when parking by row for one orientation and by column in the other orientation. The two corresponding solutions are compared to determine which way leaves the largest area of free space. Only the largest of each comparison is kept for parking future aircraft. The second way space is reserved is in the partially empty rows. If there is any unused space in each row, it is reserved as a partially filled row. For an aircraft to be parked in the partially empty row, the following conditions need to be met. First, the parking style must be equal to or less restrictive than the parking style used to create the row. Second, the length of the aircraft to be parked must be equal to or less than the length of the aircraft type used to create the row. Finally, to determine the number of the aircraft type that fit, the width of the free apron space is divided by the sum of the width of the aircraft and its wingtip safety distance.

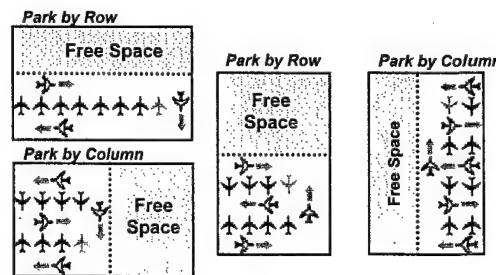


Figure 13. Free space and partly empty rows

When an aircraft type is to be parked, each stored parking solution is checked to see how many aircraft can be parked on it. This value is found by summing the number that will fit in the partially empty rows and the number that will fit on the rectangular free space of the apron. All of the parking

solutions are compared to find the maximum number that can be parked on the apron.

As different sets of aircraft are parked on the apron, the number of possible parking solutions expands by a factor of two. In other words, the maximum number of parking solutions is 2 raised to the number sets of aircraft parked. To prevent an excessive number of solutions slowing down system resources, a maximum number of solutions to keep can be defined. To determine which solutions to keep, the maximum number of aircraft that can be parked is used as a scoring factor. The solutions with the highest scoring factor are kept.

All of the possible solutions currently saved are checked to determine how many of the aircraft type can be parked. Then the maximum quantity of all of the possible solutions is returned as the maximum number that can be parked on the apron.

The visual example from the previous section is continued for this phase of the heuristic.

STEP 4- The example continues with the user deciding to park seven aircraft on the apron. The left side of Figure 14 shows how the aircraft are parked first filling by columns, and then filling by rows. After the apron is rotated, the right side depicts how the aircraft are parked by filling the rows first and then the columns. The free space for each parking solutions is indicated by the dotted line. The grayed out aircraft in some of the parking spots indicate the empty space of a partially empty rows.

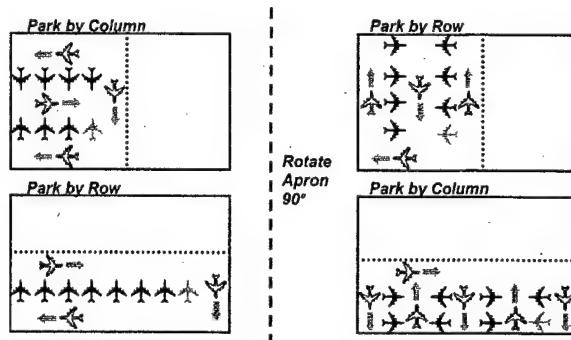


Figure 14. Step 4-Park 7, 4 possibilities

STEP 5- The free space on the parking solutions is compared in Figure 15. The solutions on the top are compared, and the parking solutions on the bottom are also compared. For this example the parking solutions in the upper left corner and the lower right corner have the larger rectangular free space.

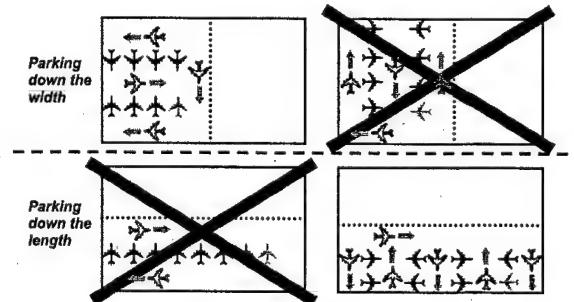


Figure 15. Step 5-Eliminate smaller free spaces

STEP 6- Figure 16 displays the next aircraft type to be parked on the apron, also included are the previously saved parking solutions.

STEP 7- First the partly empty rows are checked in Figure 17 to see if any of the aircraft will fit on the row. Since the aircraft is larger than the aircraft type used to create the row it will not fit.

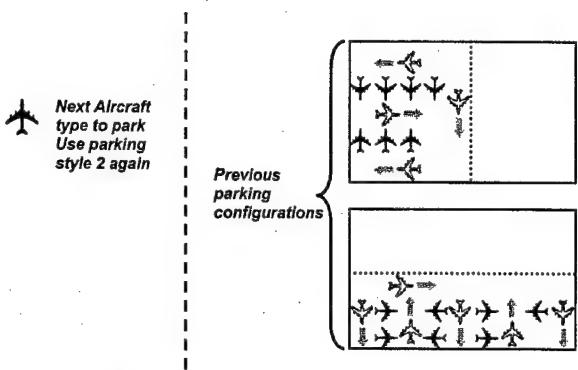


Figure 16. Step 6-New aircraft to park

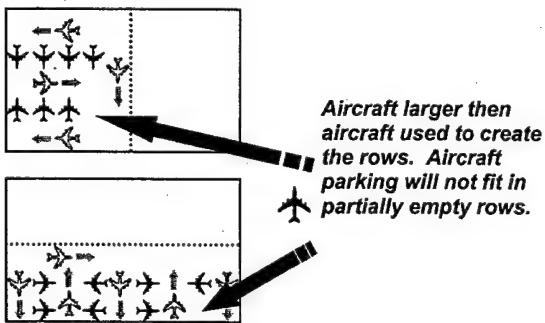


Figure 17. Step 7-Check partly empty rows

STEP 8- Next the free rectangular space is checked. Since taxiway space is required for the parking style, the free space is checked to see if there are any adjacent taxiways. Since the adjacent taxiway space is not wide enough for the new aircraft type, it is widened so that both aircraft types can use it, as shown in Figure 18.

STEP 9- Now the number of rows and columns that can fit is found, taking into account rotation. The maximum for all of the configurations is now found by summing the number that can fit on the partially empty rows, with the amount that can fit on the free space. As shown in Figure 19, the maximum that can be parked is 3.

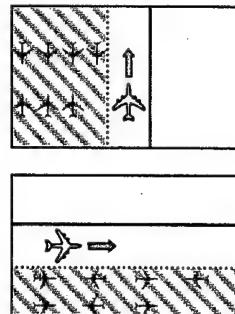


Figure 18. Step 8-Expand shared taxiway

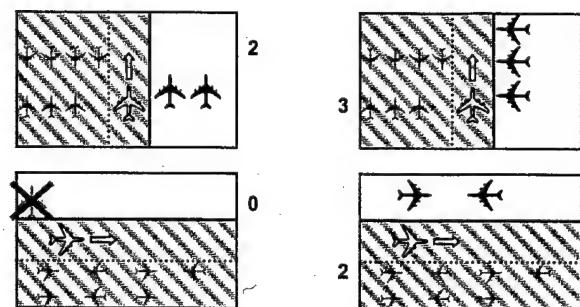


Figure 19. Step 9-Build possible configurations

At this point the user could select to park between 1 and 3 aircraft on the apron. If three aircraft are to be beddown, then only the solution shown on the upper right of Figure 19 would be used. If 1 or 2 aircraft were chosen, then variations on all but the lower left corner would be made, and a total of four parking solutions would be generated.

#### Phase III: Multiple aircraft types/Multiple Aprons

Up to this point, we have been focusing on parking on an individual apron. Now the process is expanded to park on multiple aprons, since most airfields have more than one apron available.

Currently a set of rules is used to determine which aircraft will be parked on which aprons. Once assigned, aircraft are currently not moved between aprons. It is recognized though, that this could result in the ability to park additional aircraft. However, it was decided to develop a simple approach first, and then, if needed the process can be further refined.

The rules used to match a set of an aircraft type to the aprons are as follows. If possible, all of the aircraft are parked on the smallest apron that can park the entire set. The smallest apron is defined as the one that can park the fewest of this aircraft type. If all of the aircraft to be parked can not be parked on one apron, then the aircraft are iteratively parked on the smallest apron that can park at least one of the aircraft, this is repeated until there are no more aircraft left to park.

The process outlined in phase two is used to calculate how many aircraft can fit on the apron. Once aircraft are parked on a specific apron, the process in phase 2 is again used. Aircraft stay on the apron they are parked on. When more aircraft are parked at the airfield, this process does not move aircraft between different aprons to improve the number of additional aircraft that can be parked.

#### Dynamic Parking Tables

The specialized heuristic outlined in the previous section provides the engine for building a beddown at an airfield. The purpose of the dynamic parking tables is to provide the user with an interactive picture of their beddown plan, as they build it. It shows where the aircraft can and should be beddown. When the user decides to beddown aircraft at an airfield, the tables show the reduced capability of the airfield to accept other aircraft. The tables also show what targets are within range of the aircraft, if it is beddown at each airfield.

One of the tables shows the maximum quantity that can be parked. The purpose of this table is to display the number of each aircraft type that can be parked at the airfield, if nothing else is parked there. This table provides the user an idea of the capability of each airfield.

The maximum parking table lists the different squadrons of aircraft across the top,

and the different airfields along the side. Each cell in the table represents an airfield-aircraft combination. To determine what is displayed in the cell, the following steps are followed. First the runway at the airfield is checked to see if it meets or exceeds the minimum requirements for length, width, and LCN (how hard it is) for the aircraft type. If the runway is not sufficient, then the cell is shaded red and no further work is done.

If the runway is sufficient, the parking heuristic is used to determine the quantity of the aircraft that be parked at the base. This value is displayed in the cell. If the number is less then the number to be parked, the cell is shaded orange.

If there is enough room to park the squadron of aircraft at the airfield, then the refueled range of the aircraft is estimated and used to determine what targets are within the range of the aircraft, if assigned at this airfield. To estimate the refueled range of an aircraft, the combat range of the aircraft is tripled. If the aircraft is not within range of any of the targets, the cell is colored yellow.

If any targets are within range of the aircraft, their ID's are listed inside of the cell, after the quantity of aircraft to be parked. If one or more of the targets are within range, then the cell is colored green.

The beddown table is the table that is actually used to park the aircraft at the different airfields. The table is initially similar to the maximum parking table, if nothing has been parked at any of the airfields. The only other difference is that it doesn't list the targets that are within range. The value it displays in the cell is the number of that aircraft that can be parked, given what has already been parked at the airfield. When no aircraft have been parked at the airfields, then the numbers in the beddown table will be identical to the maximum parking table.

To beddown aircraft at an airfield, the user double clicks on the cell corresponding to the aircraft and airfield. If this is an allowed location, the value in the cell will change to the number of aircraft that have just been parked. The cell is shaded green, to represent that the aircraft are parked at this airfield. The other cells for the aircraft are shaded grey, showing that they no longer should be considered. For the remaining cells corresponding to the airfield, the number of aircraft that can be parked at the locations is updated to take into account the aircraft now parked at the airfield. To do this, the heuristic is rerun with the new aircraft parked at the airfield. The user also has the option of unparking aircraft at a location, or resetting the entire beddown and starting over.

By having the two different tables, the user can compare the initial starting conditions, with their current beddown plan, to get a feel for other possible bedowns.

The following figures are a notional example of how the dynamic parking tables work. Figure 20 contains both the maximum parking table on the top, and the actual parking table, MDS (Mission Design Series) Parking on the bottom. A random set of aircraft is listed across the top, and several African airfields are listed along the left side. The first number listed in each of the data cells of the table is the maximum number of corresponding plane type that can be parked at each location. For example, under the "4 C-141" column, the first data cell contains a "23." This means that if nothing else was parked at Bole Intl, 23 C-141s could be parked there. Many of the data cells in the top table also contain additional values. These values correspond to notional targets that are within range of that aircraft type, at that airfield. For example, in the same data cell before under "4 C-141" the remaining data is "/ 1, 2", which means that if the C-141s are parked at

Bole Intl, they will be within range of targets number 1 and 2. Data fields that do not contain any values are colored red. This indicates that the runway at that airfield does not meet the recommended requirements for that aircraft type. For example the runways at only two of the airfields are sufficient for the B-52.

To park aircraft at an airfield the user uses MDS Parking table. The user double clicks on the data cell that corresponds to the airfield and aircraft to be beddown. For example, if the user were to go to the "4 B-52" column and double click on the "16", corresponding to Bujumbura Intl, Figure 21 would be the result. Now instead of showing the number that could be parked, the cell contains the number of aircraft actually parked. The impact of bedding down the aircraft at that location can be found by comparing the remaining data cells for "Bujumbura" with their previous values. Instead of 18 C-141s, now only 14 C-141s can be parked there, and so on. Figure 22 shows an example of a completed beddown.

	4 B-52	4 C-141	2 C-17	4 E-3	6 F-15E
BOLE INTL [JWKE]	16	23	20	5	131
BUJUMBURA INTL [CSWJ]	18	18	8	21	73
ENTEBBE INTL [GBXAJ]	16	12	21	98	
GAROUA [HSMZ]	6	5	5	5	52
LUSAKA INTL [NUWA]	6	10	7	10	70

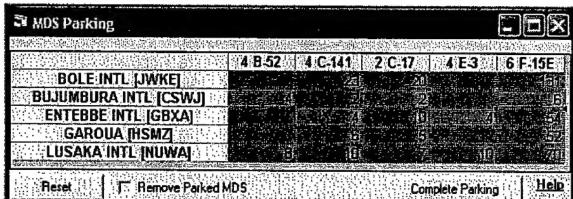
  

	4 B-52	4 C-141	2 C-17	4 E-3	6 F-15E
BOLE INTL [JWKE]	16	23	20	5	131
BUJUMBURA INTL [CSWJ]	18	18	8	21	73
ENTEBBE INTL [GBXAJ]	16	12	21	98	
GAROUA [HSMZ]	6	5	5	5	52
LUSAKA INTL [NUWA]	6	10	7	10	70

Figure 20. Example Dynamic Parking Tables

	4 B-52	4 C-141	2 C-17	4 E-3	6 F-15E
BOLE INTL [JWKE]	23	20	5	5	131
BUJUMBURA INTL [CSWJ]	14	5	5	5	49
ENTEBBE INTL [GBXAJ]	16	12	21	98	
GAROUA [HSMZ]	6	5	5	5	52
LUSAKA INTL [NUWA]	10	7	10	10	70

Figure 21. Example 4 B-52s parked



**Figure 22. Example Complete Beddown**

## TESTING

A majority of the testing done to date has been to verify that the results generated correspond to the parking styles. For validation testing, results from CBLP have been compared to real world beddown plans. At airfields where ramp space was a constraint, CBLP generated similar results.

More stringent validation testing is on hold until CBLP is enhanced to display an image of the beddown plans generated for each apron. This enhancement will significantly speed up the validation process by allowing planners to judge the actual parking plan built, rather than by simply comparing the quantity generated.

AFSAA has used the improved version of CBLP in several analysis projects, where it has proved to be very useful. One of the projects looked at the ability to add additional aircraft to an existing beddown. The results produced by CBLP were very close to the final results produced.

## FUTURE IMPROVEMENTS

Further major improvements in capability and minor refinements in existing capabilities are planned for CBLP. As mentioned before, one of the next minor steps is to display the parking plans that are created by the heuristic. Currently the code doing the heuristic already has the functionality to store where it is placing the aircraft; all that is needed is to build the display interface. An additional refinement is to allow the user to choose which of the four parking styles to use, rather than limiting them to one style. It is important to

have the capability to display the parking plans, because it will allow the planners to better judge which parking styles they should use.

Incorporating fuel constraints into the beddown picture is another area of improvement in capability planned. Including the fuel requirements and storage capacity will allow planners to determine if there is enough fuel to conduct the planned number of sorties. It is important to note that fuel bladders are common way of quickly expanding the fuel storage capacity of an airfield. The purpose of the including the fuel will not be hard restriction, instead it will be to highlight potential problems that the planners will need to take into account.

Further improvements will involve additional research in other areas that impact beddown planning. Those areas include munitions, airfield infrastructure, and other MOG (Maximum On the Ground) related constraints that impact the type and number of aircraft to beddown.

Research is also needed on factors that impact which airfields are available to beddown aircraft at. An example is how friendly the host country is, which is represented by the country's threat level. Even if the host country allows access to airfields, they might restrict combat operations at airfields that are near large cities.

Funding has recently been allocated to develop a web-based version of CBLP. CBLP is currently written in Visual Basic, web-basing CBLP will involve rewriting CBLP into JAVA. The web-based version of CBLP will be demonstrated in JEFX 04 as part of the C2 Battlelab's VEST initiative. CBLP will be used to provide an analytical capability for the expeditionary site planning tools. Operational testing of the web-based version is planned for February-March 04. JEFX 04 is in July-August 04.

## CONCLUSION

The improvements made to CBLP increased AFSAA's ability to create realistic beddown scenarios, both for current operations and in analysis of future scenarios. While the parking heuristic is not designed to create a final beddown plan, it does create a conservative starting point to build upon. While more validation of the beddown estimates is needed, we are more confident in the results we are getting with the enhanced version of CBLP. Future enhancements will continue to improve the capability of CBLP to quickly and accurately estimate our ability to beddown aircraft at different locations around the world, and to make it more readily available to the Air Force through the web.

## ABBREVIATIONS & ACRONYMS

AAFIF:	Automated Air Facilities Intelligence File
AFSAA:	Air Force Studies and Analyses Agency
C2:	Command and Control
CAPP:	Contingency Aircraft Parking Planner
CBLP:	Capabilities-Based Logistics Planner
JEFX:	Joint Expeditionary Forces Experiment
LCN:	Load Classification Number
MDS:	Mission Design Series
MOG:	Maximum On the Ground)
NIMA:	National Imagery and Mapping Agency
VEST:	Visualization of Expeditionary Sites Tools

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## DESCRIPTORS

Logistics  
Beddown  
Planning  
Aircraft  
Parking  
Heuristic